Microelectronics Radiation Hardness: Test Set-up for the ALICE Pixel detector

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Abstract

Two different test apparatus were set up to check the radiation hardness of the pixel detector electronic components designed for the ALICE ITS. Motivations and the main features are described as well as results we reached. Preliminary results on the OMEGA3/LHC1 chip are also presented.

1 Introduction

From the anticipated beam allocation described in the ALICE Technical Proposal [1] and the expected energy deposition calculated by using a set of simulated events [2], we may assume for the first ten years of operation a figure of 200 krad as upper limit of the total integrated dose.

A reasonable scenario for the irradiation of the detectors is the following: they will be exposed each year for about one month to reaction products of heavy ions collisions and for about four months to reaction products of proton collisions. Five years are reserved to the Pb-Pb, two and half to the Ca-Ca at high luminosity and the other two and half to Ca-Ca at low luminosity. In such a case they should receive during a month a dose depending on the beam and the related luminosity as follows: 7.5 krad for Pb beams, 1 krad for p beams and 47 krad for high luminosity Ca beams. Finally, one can assume that Pb-Pb collisions will be taken at the beginning, follows Ca-Ca firstly at low luminosity, then at high luminosity (Fig.1).

It is known that, after the exposure, the annealing process allows a partial recovery of the induced damage, the effectiveness of this depends on the time elapsed after exposure and conditions of detector storage. This kind of dependence, however, is still far from being parameterized. Some standard tests exist, but they mainly help in the evaluation of the behaviour of chips made by using different manufacturing technologies and/or irradiated in different exposure conditions. Therefore it is very difficult to guess from the existing data the effect of the radiation damage on chips built by using a new technology. Furthermore it is well known that chips coming from the same batch show a different behaviour with respect to the radiation damage.

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For these reasons we considered the opportunity to perform some measurements to check the radiation hardness of the read-out chip electronics which is being developed for the ALICE pixel detectors.

2 Requirements

The research on the radhard micro-electronics technology is at the beginning and the study of the damage mechanisms just started [3]. Our rough estimation of the exposure to the radiation of the pixel detectors which will operate in the ALICE experiment indicates that the total integrated dose should be relatively small. However, the expected cumulated dose is large enough so that the use of detectors presently available cannot be considered. Therefore, the development of new manufacturing method is necessary, although, probably it will require only minor modifications of the presently used technology. We should not need, in this case, a detailed study of the behaviour of each electronic component, an estimation of the overall resistance of the read-out chip could be sufficient.

In the irradiation tests it is very difficult to reproduce the real time dependence of the damage and the annealing as well as the energy released by the minimum ionizing particle (M.I.P.) that constitutes most of the emitted particles in the ALICE experiment. So, the method usually adopted to check the detector hardness is to deposit in short time the total dose which is expected to irradiate the chips during their life time. This procedure, in fact, is considered to be more damaging than the real one.

For this purpose we have prepared two different set-up's to study the damage induced by gamma rays and ionizing particles. The main effect of particles and gammas impinging on the micro-electronics layer is on surface rather than in the bulk as is the case for the silicon detectors, so that we are confident that the use of low energy ionizing particles instead of M.I.P. is not a severe limiting factor for our study.

The wide range available in the total dose and the dose-rate allows us to study extensively the damage as a function of the dose-rate. The combination of different total dose and annealing time intervals should indicate whether we are able to describe the detector behaviour under different conditions and finally to parametrize them. Another interesting point is to compare the damage produced by photons and by charged particles. Finally, as the result could be different for similar chips, we want to analyze the behaviour of many chips to get a significant statistics.

3 Setups

3.1 The gamma ray set-up

This test facility is based on a GAMMACELL 220 located at the Istituto Superiore di Sanita' in Rome which produces gamma rays of 1.173 and 1.332 MeV from a ^{60}Co source. It delivers a "uniform" dose-rate in air of 0.0114 krad/s at the centre of a cylindrical volume, 15 cm in diameter and 40 cm in height. The dose uniformity inside a cylindrical volume of 3 cm radius and 4 cm height is better than 5%. Due to mechanical constraints, the minimum exposure time is of the order of 6 s, that corresponds to 0.068 krad. The space available and the in-out displacement system allows easily to power the chip during exposure without any read-out.

3.2 The proton beam setup

Our test facility is set up at the 7 MV CN Van der Graaf accelerator of the Laboratori Nazionali di Legnaro of the INFN which can deliver proton beams with an intensity ranging from 100 to 1000nA. We performed the irradiation by using the Rutherford scattering of a 6.5 MeV proton beam on a Au target, placing the chip detector at forward angles. At this bombarding energy, no nuclear reaction channels are open. This method makes available a wide range of dose rates varying the irradiation angle and the beam intensity.

An existing scattering chamber of 80 cm in diameter was modified in order to allow the powering and the read-out of the chip during the exposure. Inside, the chip was positioned at 30°, distant 21.8 cm from the target, so that it subtended an angular interval of $\pm 1°$. In this way the variation of dose received by the ends of the chip was with respect to the center $\pm 13\%$. Before irradiation the beam was aligned and focused by using a double collimator, and also the incertainty of the beam impinging point on the target was limited to ± 1 mm and the corresponding incertainty induced in the estimation of the total dose was 4%.

Due to the limited beam-time we used a high dose-rate bombarding a relatively thick target (13 mg/cm^2) with an intense beam (1 μA). The thickness of the target, however, did not cause a noticeable spread in the proton kinetic energy and serious error in the dose calculation.

To monitor the irradiation and to calculate the total dose we measured, with a silicon surface barrier detector (SBD), the energy spectrum of the particles outgoing at 150°. This large angle was chosen to minimize the rate on the SBD in order to reduce the dead-time of the acquisition. At 150°, however, the energy spectrum has a different shape with respect to the spectrum at 30°, both for the elastic peak and the quasi-flat background. So, in the calculation of the total dose taken by the chip the largest incertainty is due to the estimation of the background contribution at 30° starting from the observed spectrum at 150°, because it is not possible to scale it with the Rutheford scattering cross-section. Fortunately at 30° the ratio between the elastic peak and the background is about 18 and we estimated an error in the dose calculation, caused by the presence of background, of $\pm 3\%$. So, the sum of the experimental errors is comparable to the one ($5\div 10\%$) of the literature value for the proton stopping-power in silicon at 6.5 MeV [4].

4 Preliminary tests on some OMEGA3/LHC1 chips

4.1 Generalities

Details on the ASIC OMEGA3/LHC1 chips tested on our set-up's can be found in [5]. The strategy adopted during the test on the chips consists in monitoring the chip currents and checking the functionality of the whole chip. The chip is powered during the study and the logical states of the chip are investigated, in particular varying the five bias voltages. These biases are set for detector leakage current compensation at the level of the preamplifier input (VCOMP); for the gain of the preamplifier (VBIAS), for the discriminator threshold (VTH) and finally, one for the coarse delay (VDL) and one for the fine delay adjustment (VDLA). Both "digital" and "analogue" chip currents are monitored during and after the exposure. This procedure allows to point out the possible recovery caused by the annealing at fixed temperature and dose rate. For both setups the consistency of the dose calculation was checked by a dosimetry measurement done by TLD's.

4.2 Results obtained with gamma irradiation

The "digital" current (indicated by I(at bias of +3.5V)) studied as function of the cumulated dose shows (Fig.2a) a regular increase although with different slopes after an initial threshold in dose of about 10 krad. The variation is of about one order of magnitude for the first 50 krad. The corresponding plot for the "analogue" current (indicated by I(at bias of +1.5V)) shows a more significant behaviour (Fig. 2b). Here the initial, nearly constant region, is more extended, up to 20-35 krad, followed by a variation of several orders of magnitude in a short dose interval of about 5-10 krad.

The annealing study starts shortly after the end of the irradiation and shows generally a shorter recovery time for lower cumulated doses than for the higher ones. In an interval of 30-70 hours at room temperature the annealing takes place, then the currents maintain the reached values. The functionality check (Fig. 3a) is performed using the standard read-out system based on VME, setting by software the five bias voltages and the delay adjust register, for each pixel, to zero. The strobe width used was 800 ns. When a total cumulated dose of 20 krad was reached, just after the irradiation only noisy pixels were detected (62 out of 2048 cells of the total matrix); no dead pixels were observed. After one week the noisy pixels were reduced to 41; still no dead pixels appeared (Fig.3b). Concerning the dispersion in timing homogeneity, just after one day of annealing it reaches 80% of the pre-irradiation figure (Fig. 3a). For cumulated total doses of more than 40 krad all pixels were found dead without any annealing effect after one week at room temperature.

4.3 Results obtained with proton irradiation

The results obtained with the proton irradiation (Figs. 4) suggest that the damage suffered by the chip is different from the one induced by the gammas.

The "digital" current (Fig. 4a) remains practically constant up to 25 krad and then increases by an order of magnitude at about 50 krad. Also the "analogue" current (Fig. 4b) does not show a significant deviation from the nominal value until 25 krad and, for higher doses, continuously decreases indicating a progressive loss of functionality of the read-out electronics.

The behaviour of the chips during the annealing phase (at room temperature) seems to be different for proton and gamma irradiations. Figs. 4c-d show the efficiency of the read-out electronics, at different times after the irradiation, as a function of the test pulse amplitude and of the trigger read-out delay. For chips irradiated with a proton dose of $\simeq$50 krad the recovery of the functionality is evident after few hours from the irradiation, whereas for chips irradiated with $\simeq$40 krad of gammas no annealing appears still after a week. Moreover, for proton irradiated chips, the recovery of efficiency exceeds 80% after about 20 days. So, it appears that the damage induced by protons and gammas is different although it is necessary to note that it is also possible the chips manufactured in the same way could have different behaviour. A minor chip damage for low-energy proton irradiation, with respect to the gammas, was found also in [6]. This effect was tentatively associated to charge recombination. Therefore, irradiations with gammas and protons allow to control the damage over a wide range of stopping-power, varying from M.I.P. to low-energy particles.

In the present work we have demonstrated that using gamma and proton irradiation we can cover a wide range of energy deposition, from the minimum of ionization to the ionization corresponding to low energy particles that will also be present in the ALICE ITS.

References

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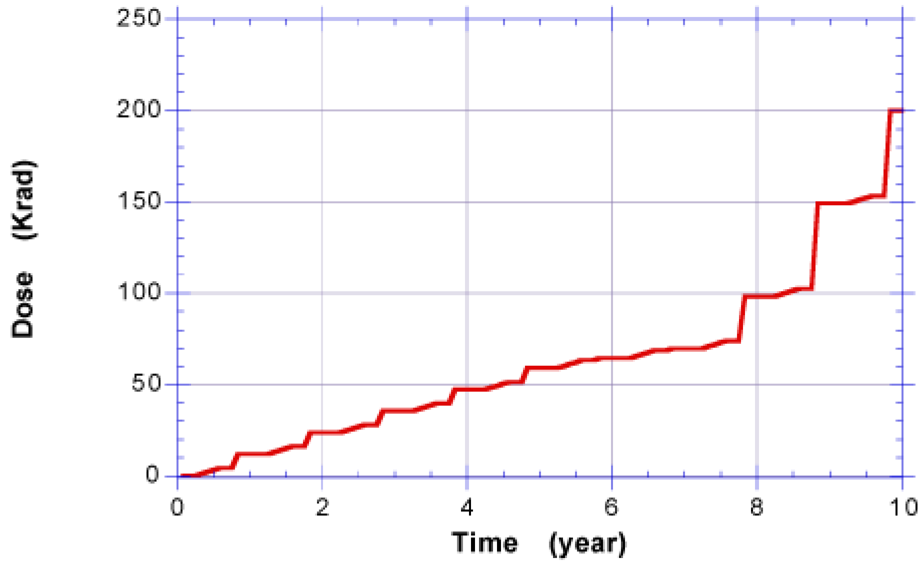

Figure 1: Expected irradiation dose in ten years for the first layer (r=3.9 cm) of the pixel detectors operating in ALICE.

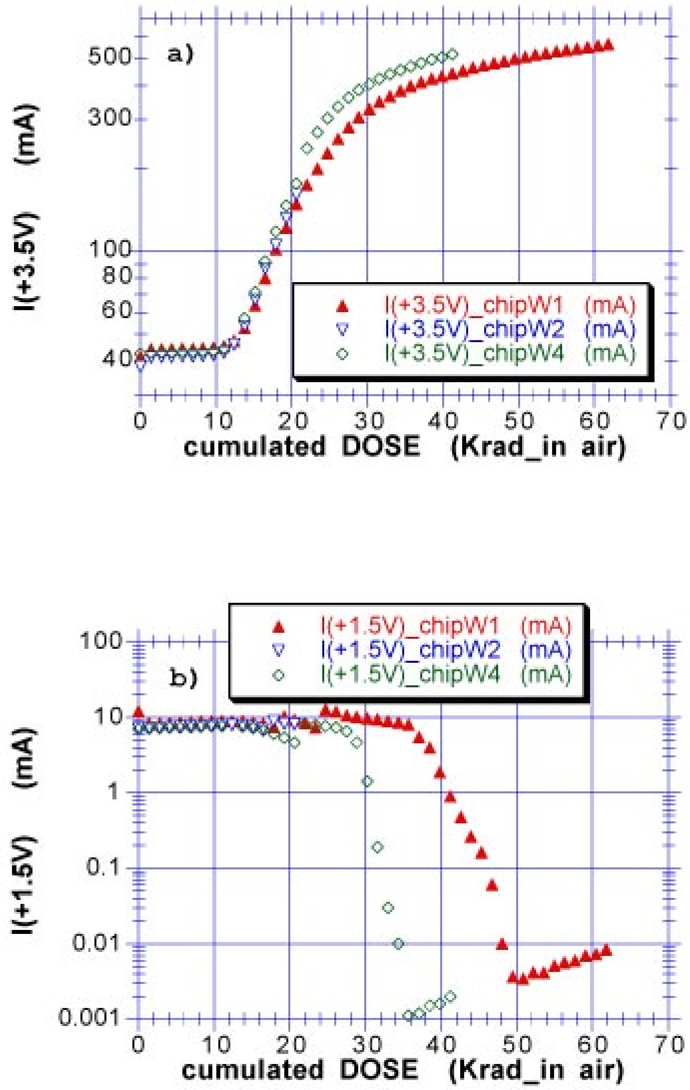

Figure 2: a) Chip digital part current (at bias of +3.5V) and b) chip analogue part current (at bias of +1.5V) as function of the cumulated dose for gamma irradiation.

Figure 3: Pixel efficiency as a function of the strobe delay a) and the annealing elapsed time b) after gamma irradiation.

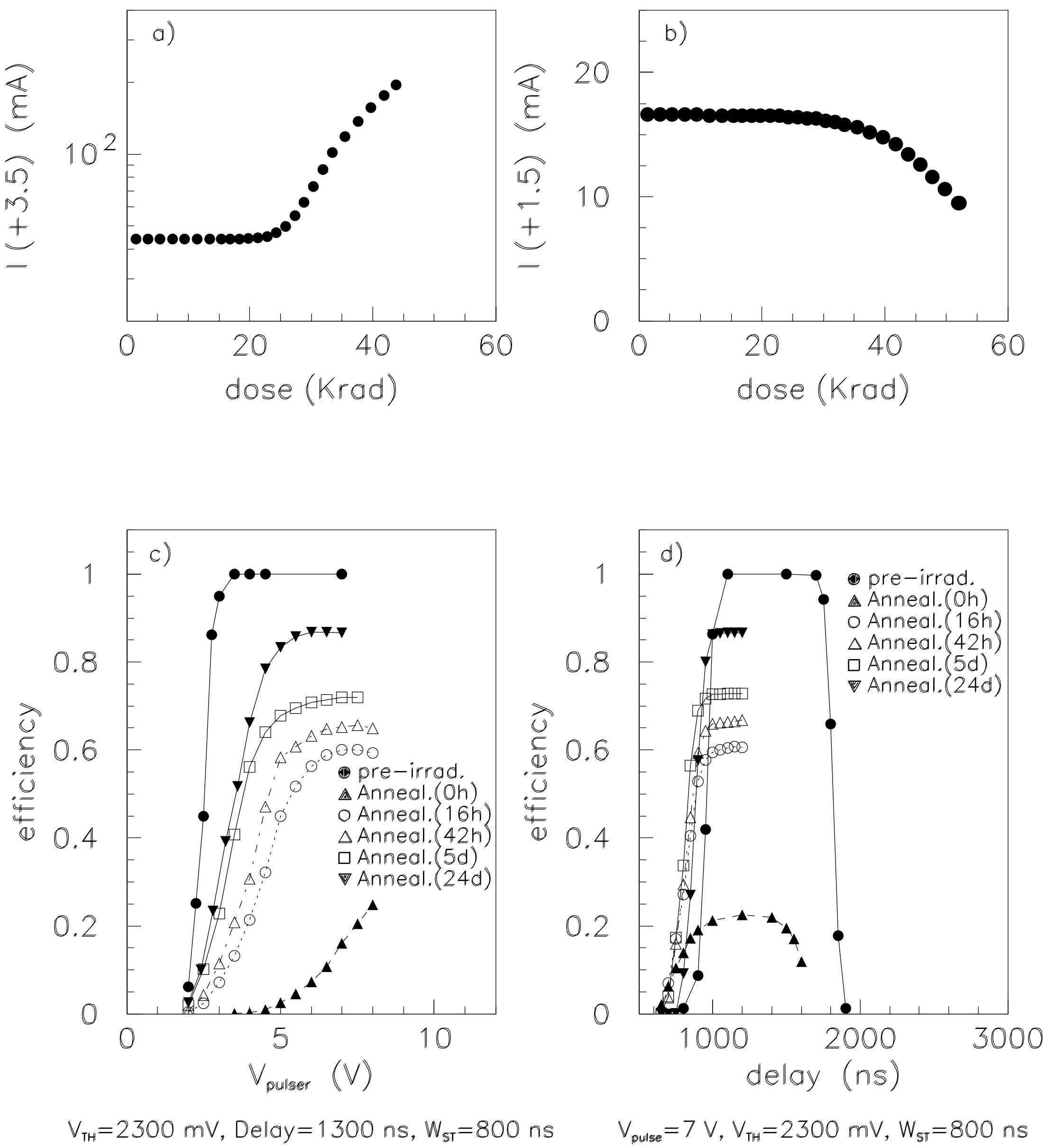

Figure 4: a) Chip digital part current (at bias of +3.5V) and b) chip analogue part current (at bias of +1.5V) as function of the cumulated dose for proton irradiation. Pixel efficiency, at different time intervals after proton irradiation, as a function of the strobe delay d) and the threshold scanning c).